COMMISSIONING OF THE NEW HEAVY ION LINAC AT THE NICA PROJECT

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Abstract

The new accelerator complex Nuclotron-based Ion Collider fAcility (NICA) is now under development and construction at JINR, Dubna. This complex is assumed to operate using two injectors: The modernized Alvarez-type linac LU-20 as injector of light polarized ions and a new Heavy Ion Linear Accelerator HILAc-injector for heavy ions beams. The new heavy ion linac, which accelerates ions with q/A-values above 0.16 to 3.2 MeV/u, is under commissioning. The main components are a 4-Rod-RFQ and two IH-drift tube cavities, operated at 100.625 MHz. Most recent results of the HILac commissioning with a carbon beam from a laser ion source are discussed.

INTRODUCTION

For the NICA collider ion beams from p to Au at energies from a few hundred MeV/u up to a few GeV/u. will be delivered by two superconducting synchrotrons- the Booster (magnetic rigidity is 25 Tm) and the Nuclotron (45 Tm) and 2 injector linacs [1]. The beams will be created by three new ion sources: SPP (Source of Polarized Particles), LIS (Laser Ion Source), Krion-6T (ESIS type heavy ion source). The ion sources will feed 2 linacs: The existing linac LU-20 with a new RFQ as front-end and the new heavy ion linac – HILac. The HILac design and development was performed by Bevatech GmbH [2] and described in detail in [3]. HILac commissioning with a C^{3+} beam from the laser ion source are presented. Parameters for HILac are given in table 1.

Table 1: HILac Parameters

Target Ion	Au^{32+}
A/q	6.25
Current	< 10 emA
Pulse length	10 µs – 30 µs
Rep. rate	< 10 Hz
LEBT energy	17 keV/u.
RFQ energy	300 keV/u.
LINAC output energy	3.2 MeV/u.

ION SOURCE & LEBT

The LIS is based on a commercially available Nd-YAG laser LPY 7864-2 The laser was tested at its operational regimes producing carbon ions at a test bench (Fig. 1).

The HILac LEBT with a length of about 2 m is split into 2 main parts. Part 1. is an electrostatic section the second part uses 2 magnetic solenoids. with a maximum magnetic field of 1.23 T. The whole LEBT has been simulated for investigating the beam matching into the RFQ acceptance (Fig 2).

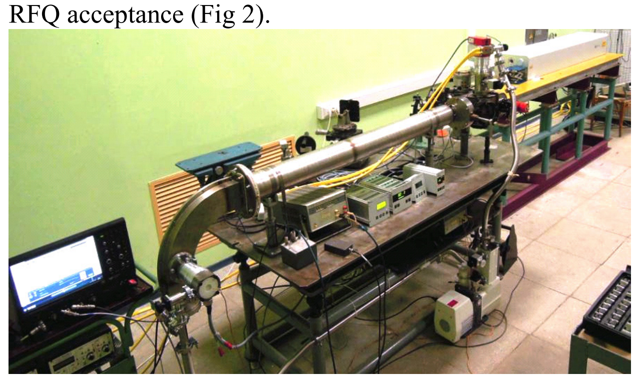

Figure 1: Nd-YAG laser at the test bench.

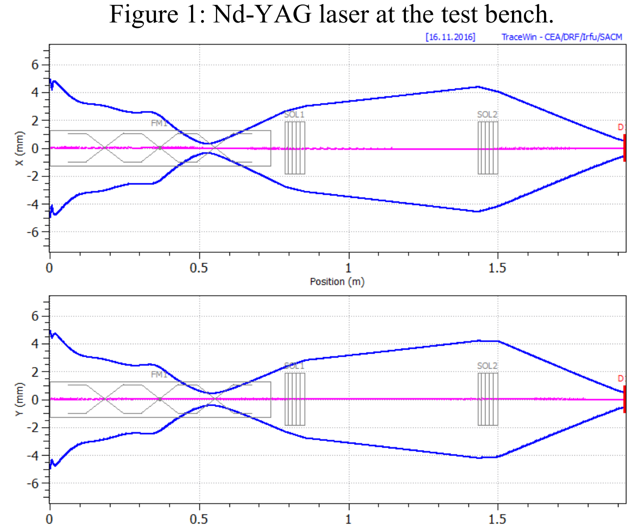

Figure 2: Matched case (rms envelope) for C^{3+} beam along the LEBT into the RFQ acceptance.

MEBT

The MEBT is equipped with two identical pulsed quadrupole-doubletts located in front and behind the

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rebuncher. The rebuncher is built as a 4-gap quarter-wave resonator powered by a kW amplifier. An impulse current transformer is located directly behind the RFQ and a phase probe is located after the second quadrupole doublet. In combination with two other phase probes, one in between the 2 IH drift tube linacs and one after the second IH DTL, the probes allow TOF beam energy measurements. To overcome angular deviations from the beam axis at the MEBT entrance a magnetic-steerer has been added into the beam-line.

RFQ

The HILac RFQ is a 4-rod structure operating at 100.625 MHz. The RFQ tank is a 3.16 m stainless steel tank of 0.35 m in diameter which is copperplated inside. The RFQ was commissioned using high power up to 120 kW and is driven by a 140kW solid state amplifier

IH-DRIFT TUBE SECTION

The MEBT is followed by 2 Interdigital H-type cavities (IH) with 2.42 m and 2.15 m outer length, respectively (see Fig. 3). The first IH tank contains an internal quadrupole triplet lens. The final energies are 1.87 AMeV after IH1 and 3.2 AMeV after IH2. For the design A/q – value of 6.5 the sum voltage gain is 20.8 MV. Both IH cavities are powered by 340 kW solid state amplifiers, one for each cavity.

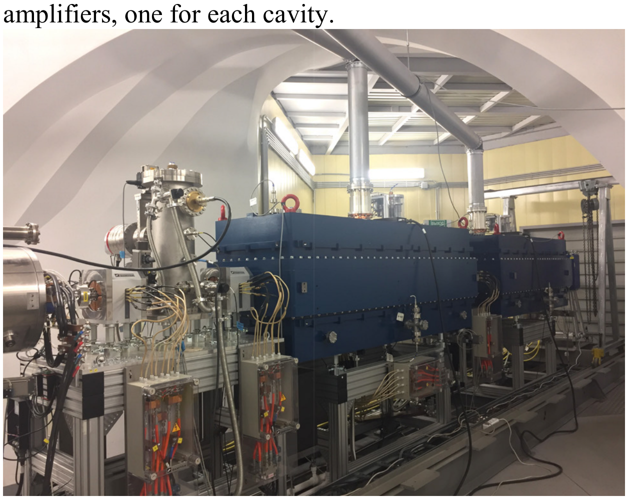

Figure 3: Interdigital H-type cavities IH1 and IH2 at JINR

COMMISSIONING

RF Commissioning

All solid state power amplifiers have been pre-tested with full power on a water load and a calibrated bi-directional coupler. Additionally a cavity with a Q factor of around 7000 has been used to test sensitivity and behavior in the matched- and unmatched case. In a stress test the 140 kW RFQ amplifier and the two 340 kW IH DTL amplifiers were driven with 5-10% excess power. Long term stability tests at 90% full power have been performed over 2 days. A digital Low Level RF system developed by ITEP [4] and also in use at LU20 of the JINR facility is providing amplitude and phase adjustments all cavities

After installation of all amplifiers, connectivity to LLRF system, rigid lines and HILac cavities at JINR, the pre-conditioned cavities were tested successfully up to full power.

RFQ Commissioning

Before installing the IH cavities the RFQ has been tested with beam. The beam energy was measured with a magnet spectrometer to be 300 keV/u ± 3% . The beam injected into the RFQ contained a mixture of carbon ion species C^{3+} and C^{2+} from LIS (Fig. 4). The total RFQ beam transmission was 90%. During daily runs in August and September the RFQ demonstrated a stable operation with good reserve of rf power when extrapolated to the A/Q design value of 6.25.

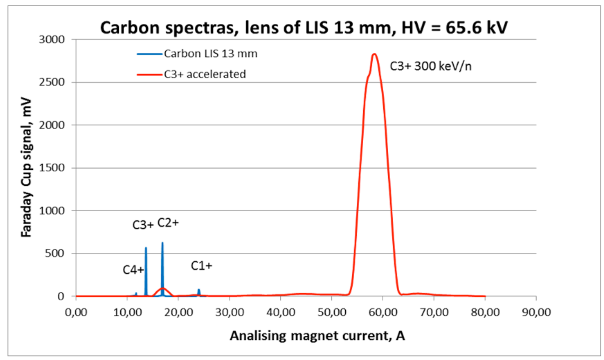

Figure 4: RFQ & MEBT with coaxial rebuncher.

MEBT Commissioning

MEBT commissioning followed beginning of October 2016. All quadrupole magnets had been tested in the factory for a alignment precision of the magnetic axis of 100 µm and a maximum tilt of 1 mrad. The alignment precision of the magnets in the beam line against the axis was validated using a laser tracker with an accuracy of 50 µm having precision markers on all beam line elements. The coaxial rebuncher showed a transient oscillation behavior with less than 5% reflected power.

IH DTL Commissioning

Phase probe signals behind the RFQ, IH1 and IH2 allowed to detect the macropulse shape as a signal envelope as well as the microbunch signal (see fig 5). Beam pulse lengths of 10 µs – 30 µs according the design specifications were measured with the phase probes. In one of the next steps these probes will also be used for TOF beam energy diagnosis during operation, once the probes and their cable lengths are calibrated and checked against the energy measurements with the magnetic spectrometer at the end of IH2. Two identical pulsed current transformers (ICT made by BERGOZ), one in the MEBT and one after IH2, allow to measure Linac beam transmission.

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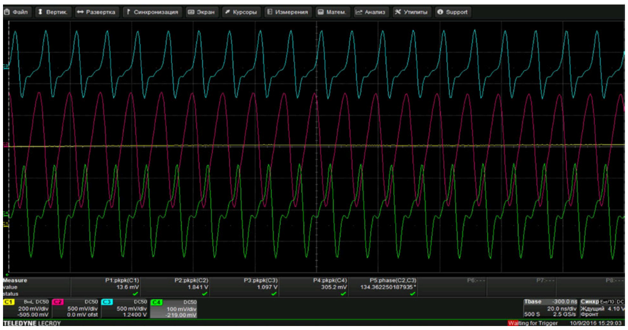
Figure 5: Phaseprobe signals: red – behind RFQ, green – behind IH1, blue – behind IH2.

Fig. 6 is from the last day of measurements on HILAc. Displayed are the signals from current transformers in MEBT and after IH2, blue line – signal from Faraday cup in the spectrometer (more than 90% of the beam accelerated in spectra is after the magnet). So the transmission factor for C3+ is about 60% from RFQ exit to IH2 exit at this stage of running in.

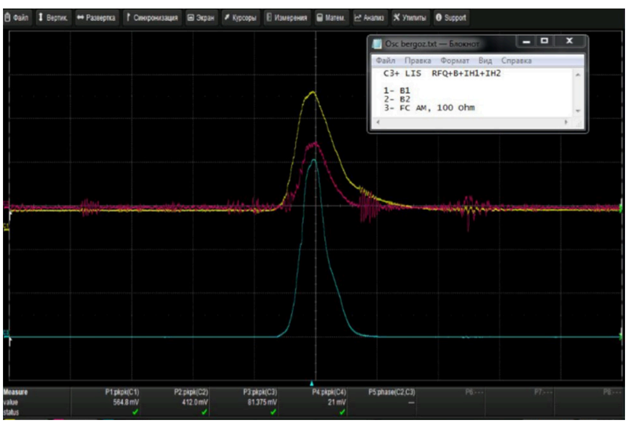
Figure 6: MEBT and IH1 ICT in yellow/red and Faraday cup at the spectrometer in blue.

Further optimization of quadrupole settings and steerer behind the RFQ allow for future improvements. In a third series of measurements the beam energy at the exit of the 2 IH cavities was validated with the magnetic spectrometer. Due to timing constraints it was not possible to optimize the spectrometer setup at its position behind IH2. The energies behind IH1 and IH2 could be verified with the spectrometer well to be at 1.87 AMeV 3.2 AMeV (Fig. 7).

SUMMARY

After 4.5 years of design and development work the Heavy Ion Linac - HILac - at JINRs new injector complex has been successfully commissioned. Ion source, LEBT, RFQ, MEBT and IH DTLs are in good agreement between simulations and measurements. The installation of the vacuum-, electrical-systems and alignment have been performed in best practice by the JINR team. Vacuum conditions were at the 10^{-8} mbar level after three days of continuous pumping. The RFQ was operated absolutely stable with a transmission of > 90% for all carbon species from the LIS mixed beam. The injector commissioning lasted 3 weeks. During this time a total transmission of accelerated beam after LEBT of more than 50% for C^{3+} was measured in first tests. The energy behind the RFQ and for each IH cavity was validated to be well in agreement with the design values. All accelerating structures, the solid state rf power amplifiers and the digital LLRF system run stable. The optimization process for HILac will start in 2017. As one of the next steps the ESIS source will be added providing beam with A/Q = 6.25 using target ions of Au^{32+} for which HILac was designed. Goal of the next steps is to optimize all settings for maximum beam transmission.

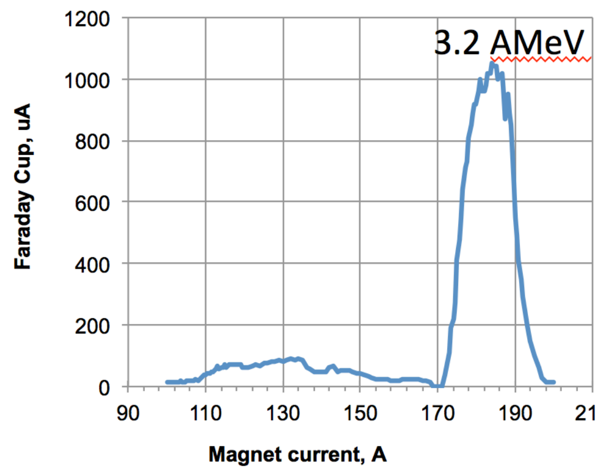

Figure 7: HILac at nominal energy.

ACKNOWLEDGMENTS


Figure 8: HILac team for commissioning.

The work on HILac has been performed in a mixed team consisting of Russian and German scientists (Fig. 8). We would like to express our best thanks for all the good work, the fruitful discussions and exchanged ideas with all team members. Our good cooperation was the basis for this successful project.

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